

Chapter 3 Multiple-Purpose Reservoirs

3-1. Hydrologic Studies for Multipurpose Projects

a. Conception. Multipurpose reservoirs were originally conceived as projects that served more than one purpose independently and would effect savings through the construction of a single large project instead of two or more smaller projects. As the concept developed, the joint use of water and reservoir space were added as multipurpose concepts. Even such competitive uses as flood control and water supply could use the same reservoir space at different times during the year.

b. Feasibility. The feasibility of multiple-purpose development is almost wholly dependent upon the demonstrated ability of a proposed project to serve several purposes simultaneously without creating conditions that would be undesirable or intolerable for the other purposes. In order to demonstrate that multipurpose operation is feasible, detailed analyses of the effects of various combinations of streamflows, storage levels, and water requirements are required. Detailed analyses of these factors may be overlooked during the planning phase because the analyses are complex and simplifying methods or assumptions may not consider some details that may be important. However, ignoring the details of multipurpose operation in the planning phase is risky because the operation criteria are critical in determining the feasibility of serving several purposes simultaneously.

c. Defining the multipurpose project. One of the factors that make detailed sequential analyses of multipurpose operation difficult during planning studies is that sufficient data on various water demands are either not available or not of comparable quality for all purposes. To adequately define the multipurpose operation, the analyses must include information on the magnitude and seasonal variations of each demand, long-term changes in demands, relative priority of each use, and shortage tolerances. Information on magnitude and seasonal variation in demands and on long-term variations in demands is usually more readily available than information on relative priorities among uses and on shortage tolerances. If information on priorities and shortages is not available from the various users, one can make several assumptions concerning the priorities and perform sequential routing studies for each set of assumptions. The results of these studies can determine the consequences of various priorities to potential water users. It may be possible for the potential

users to adopt a priority arrangement based on the value of the water for the various demands.

d. Success of multipurpose projects. The success of multipurpose operation also depends on the formulation of operational rules that ensure that water in the proper quantities and qualities is available for each of the purposes at the proper time and place. Techniques for formulating operational rules are not fixed, but the logical approach involves determining the seasonal variation of the flood-control space requirement, and the seasonal variation of conservation requirements, formulation of general operational rules that satisfy these requirements, and detailed testing of the operational rules to ascertain the adequacy of the plan for each specific purpose.

e. Multipurpose project rules. The judgment of an experienced hydrologic engineer is invaluable in the initial formulation and subsequent development and testing of operational rules. Although the necessary rules cannot be completely developed until most of the physical dimensions of the project are known, any tendency to discount the importance of operational rules as a planning variable should be resisted because of the important role they often assume in the feasibility of multipurpose projects. As a minimum, the operational rules used in a planning study should be sufficiently refined to assist the engineer in evaluating the suitability of alternative projects to satisfy water demands for specified purposes.

3-2. Relative Priorities of Project Functions

a. Developing project rules. As indicated above, the use of operational rules based on the relative priorities among the project purposes appears to offer the best approach to multipurpose operational problems. The degree of success that can be realized depends on a realistic priority system that accurately reflects the relative value of water from the project for a given purpose at a given time. Unless a realistic priority system is used to develop the operational rules, it will not be possible to follow the rules during the project life because the true priorities may control the operational decisions and prevent the project from supplying the services it was designed to provide.

b. Typical system priorities. Priorities among the various water resource purposes vary with locale, water rights, the need for various types of water use, the legal and political considerations, and with social, cultural, and environmental conditions. Although these variations make it impossible to specify a general priority system, it is useful to identify a set of priorities that would be typical under average conditions. In such a situation, operation for the safety of the structure has the highest priority unless the

consequences of failure of the structure are minor (which is seldom the case). Of the functional purposes, flood control must have a high priority, particularly where downstream levees, bridges, or other vital structures are threatened. It is not unusual for conservation operations to cease entirely during periods of flood activity if a significant reduction in flooding can be realized thereby. Among the conservation purposes, municipal and industrial water supply and hydroelectric power generation are often given a high priority, particularly where alternative supplies are not readily available. After those purposes, other project purposes usually have a somewhat lower priority because temporary shortages are usually not disastrous. It should be emphasized again that there can be marked exceptions to these relative priorities. There are regional differences in relative needs and, legal and institutional factors may greatly affect priorities.

c. Complex system priorities. In complex reservoir systems, with competing demands and several alternative projects to meet the demand, the relative priority among projects and purposes may not be obvious. The operation rules, which can be evaluated with detailed simulation, may not be known or may be subject to criticism. In these situations, it may be useful to apply a system analysis based on consistent values for the various project purposes. The results of the analysis could suggest an operational strategy which can be tested with more detailed analysis. Chapter 4 presents information and approaches for system analysis.

3-3. Managing Competitive and Complementary Functions

a. Identifying interactions between purposes. Before operation rules can be formulated, the adverse (competitive) and the beneficial (complementary) interactions between purposes must be identified. The time of occurrence of the interactions is often as important as the degree of interaction, particularly if one or more of the water uses has significant variations in water demand. In supplying water from a single reservoir for several purposes with seasonally varying demands, it is possible for normally complementary purposes to become competitive at times due to differences in their seasonal requirements.

b. Allocating storage space. When several purposes are to be served from a single reservoir, it is possible to allocate space within certain regions of the reservoir storage for each of the purposes. This practice evolved from projects that served only flood control and one conservation purpose because it was necessary to reserve a portion of the reservoir storage for storing floodwater. It is still necessary to have a specific allocation of flood-control

storage space (although the storage reservation can vary seasonally) because of the basic conflict between reserving empty storage space for regulating potential floods and filling that space to meet future water supply requirements. However, applying specific storage allocations or reservations for competing conservation purposes should be kept to a minimum because it reduces operational flexibility.

c. Operational conflicts. Allocation of specific storage space to several purposes within the conservation pool can result in operational conflicts that might make it impossible or very costly to provide water for the various purposes in the quantities and at the time they are needed. The concept of commingled or joint-use conservation storage for all conservation purposes with operational criteria to maximize the complementary effects and minimize the competitive effects is far easier to manage and, if carefully designed, will provide better service for all purposes. Where the concept of joint-use storage is used, the operational criteria should be studied in the planning process in such a way that the relative priorities of the various purposes are taken into account. This allows careful evaluation of a number of priority systems and operational plans. The operational decisions that result from such disputes are frequently not studied in enough detail (from the engineering point of view), and as a result, the ability of the project to serve some purposes may be seriously affected.

3-4. Operating Concepts

a. Operating goals. Reservoir operating goals vary with the storage in the reservoir. The highest zone in the reservoir is that space reserved at any particular time for the control of floods. This zone includes the operational flood-control space and the surcharge space required for the passage of spillway flows. Whenever water is in this zone it must be released in accordance with flood-control requirements. The remaining space can be designated as conservation space. The top zone of conservation space may include storage that is not required to satisfy the firm conservation demands, including recreational use of the reservoir. Water in this space can be released as surplus to serve needs or uses that exceed basic requirements. The middle zone of conservation space is that needed to store water to supply firm water needs. The bottom zone of conservation space can be termed buffer space, and when operation is in this zone the firm services are curtailed in order to prevent a more severe shortage later. The bottom zone of space in the reservoir is designated as the minimum pool reserved for recreation, fish, minimum power head, sediment reserve, and other storage functions.

b. Storage zone boundaries. The boundaries between storage zones may be fixed at a constant level or they may vary seasonally. In general, the seasonally varying boundaries offer the potential for a more flexible operating plan that can result in higher yields for all purposes. However, the proper location of the seasonal boundaries requires more study than the location of a constant boundary. This is discussed in more detail in Chapter 11. Furthermore, an additional element of chance is introduced when the boundaries are allowed to vary, because the joint use of storage might endanger firm supplies for one or more specific purposes. The location of the seasonally varying boundaries is determined by a process of formulating a set of boundaries and attendant operational rules, testing the scheme by a detailed sequential routing study, evaluating the outcome of the study, changing the rules or boundaries if necessary, and repeating the procedure until a satisfactory operation results.

c. Demand schedules. Expressing demand schedules as a function of the relative availability of water is another means of incorporating flexibility and relative priority in operational rules. For example, the balance between hydro and thermal power generation might well be a continuous function of available storage. As another example, it might be possible to have two or more levels of navigation service or lengths of navigation season with the actual level of service or length of season being dependent upon the availability of water in the reservoir. By regulating the level of supply to the available water in the reservoir, users can plan emergency measures that will enable them to withstand partial reductions in service and thereby avoid complete cessation of service, which might be disastrous. Terms such as desired flow and minimum required flow for navigation can be used to describe two levels of service.

d. Levels of service. There can be as many levels of service as a user desires, but each level requires criteria for determining when the level is to be initiated and when it is to be terminated. The testing and development of the criteria for operating a multipurpose project with several purposes and several levels of service are accomplished by detailed sequential routing studies. Because the development and testing of these criteria are relatively difficult, the number of levels of service should be limited to the minimum number needed to achieve a satisfactory plan of operation.

e. Buffer storage. Buffer storage or buffer zones are regions within the conservation storage where operational rules effect a temporary reduction in firm services. The two primary reasons for temporarily reducing services are to ensure service for a high-priority purpose while eliminating or curtailing services for lower-priority

purposes, and to change from one level of service for a given purpose to a lower level of service for that same purpose when storage levels are too low to ensure the continuation of firm supplies for all purposes. As with the other techniques for implementing a multipurpose operation, the amount of buffer storage and the location of the boundaries cannot be determined accurately except by successive approximations and testing by sequential routing studies.

3-5. Construction and Physical Operation

a. General. In addition to hydrologic determinations discussed above, a number of important hydrologic determinations are required during project construction and during project operation for ensuring the integrity of the project and its operation.

b. Cofferdams. From a hydrologic standpoint, during construction the provisions for streamflow diversion are a primary concern. If a cofferdam used for dewatering the work area is overtopped, serious delays and additional construction costs can result. In the case of high cofferdams where substantial poundage occurs, it is possible that failure could cause major damage in downstream areas. Cofferdams should be designed on the same principles as are permanent dams, generally on the basis of balancing incremental costs against incremental benefits of all types. This will require flood frequency and hypothetical flood studies, as described in Chapters 6 and 7 of this manual. Where major damage might result from cofferdam failure, a standard project flood (SPF) or even a probable maximum flood (PMF) may be used as a primary basis for design.

c. Overtopping. Where a major dam embankment may be subject to overtopping during construction, the diversion conduit capacity must be sufficient to regulate floods that might occur with substantial probability during the critical construction period. It is not necessary that the regulated releases be nondamaging downstream, but it is vital that the structure remain intact. An explicit evaluation of risk of embankment failure and downstream impacts during construction should be presented in the design document.

d. Conduits, spillways, and gates. Conduits, spillways, and all regulating gates must be functionally adequate to accomplish project objectives. Their sizes, dependability, and speed of operation should be tested using recorded and hypothetical hydrographs and anticipated hydraulic heads to ensure that they will perform properly. The nature of stilling facilities might be dictated by hydrologic considerations if frequency and duration of

high outflows substantially influence their design. The necessity for multilevel intakes to control the quality of reservoir releases can be assessed by detailed reservoir stratification studies under all combinations of hydrologic and reservoir conditions. Techniques for conducting reservoir stratification studies are discussed in EM 1110-2-1201.

e. Design. The design of power facilities can be greatly influenced by hydrologic considerations, as discussed in Chapter 11 of this manual and EM 1110-2-1701. General considerations in the hydrologic design of spillways are discussed in Chapter 10 and more detailed information is presented in Chapter 14 herein.

f. Extreme floods. Regardless of the reservoir purposes, it is imperative that spillway facilities provided will ensure the integrity of the project in the event of extreme floods. Whenever the operation rules of a reservoir are substantially changed, spillway facilities should be reviewed to ensure that the change in project operation does not adversely alter the capability to pass extreme floods without endangering the structure. The capability of a spillway to pass extreme floods can be adversely affected by changes in operation rules that actually affect the flood operation itself or by changes that result in higher pool stages during periods of high flood potential.

g. Special operating rules. A number of situations might require special operating rules. For example, operating rules are needed for the period during which a reservoir is initially filling, for emergency dewatering of a reservoir, for interim operation of one or more components in a system during the period while other components are under construction, and for unanticipated conditions that seem to require deviation from established operating rules. The need for operation rules during the filling period is especially important because many decisions must be based on the filling plan. Among the important factors that are dependent upon the filling schedule are the on-line date for power generating units, the in-service dates for various purposes such as water supply and navigation, and the effective date for legal obligations such as recreation concessions.

h. Specification of monitoring facilities. One of the more important considerations in the hydrologic analysis of any reservoir is the specification of monitoring facilities, including streamflow, rainfall, reservoir stage, and other hydrologic measurements. These facilities serve two basic purposes: to record all operations and to provide information for operation decisions. The former purpose satisfies legal requirements and provides data for future studies. The latter purpose may greatly increase the project

effectiveness by enabling the operating agency, through reliable forecasts of hydrologic conditions, to increase operation efficiency. Hydrologic aspects of monitoring facilities and forecasts will be presented in a new EM on hydrologic forecasting.

i. Stream gauges. Because gauged data are most important during flood events, special care should be taken in locating the gauge. Stream gauges should not be located on bridges or other structures that are subject to being washed out. To the extent possible, the gauges should be capable of working up through extreme flood events, and stage-discharge relationships should be developed up to that level. The gauge should have reasonable access for checking and repair during the flood. Reservoir spilling, local flooding, and backwater effects from downstream tributaries should all be considered when finding a suitable location. More detailed information on stream gauges can be found in many USGS publications, such as Carter and Davidian (1968), Buchanan and Somers (1968 and 1969), or Smoot and Novak (1969).

3-6. General Study Procedure

As indicated earlier, there is no fixed procedure for developing reservoir operational plans for multipurpose projects; however, the general approach that should be common to all cases would include the following steps:

a. Survey the potential water uses to be served by the project in order to determine the magnitude of each demand and the seasonal and long-term variations in the demand schedule.

b. Develop a relative priority for each purpose and determine the levels of service and required priority that will be necessary to serve each purpose. If necessary, make sequential studies illustrating the consequences of various alternative priority systems.

c. Establish the seasonal variation of flood-control space required, using procedures discussed in Chapter 10.

d. Establish the total power, water supply, and low-flow regulation requirements for competitive purposes during each season of the year.

e. Establish preliminary feasibility of the project based on physical constraints.

f. Establish the seasonal variation of the storage requirement to satisfy these needs, using procedures described in Chapter 11.

g. Determine the amount of storage needed as a minimum pool for power head, recreation, sedimentation reserve, and other purposes.

h. Using the above information, estimate the size of reservoir and seasonal distribution of space for the various purposes that would satisfy the needs. Determine the reservoir characteristics, including flowage, spillway, power plant, and outlet requirements.

i. Test and evaluate the operation of the project through the use of recorded hydrologic data in a sequential routing study to determine the adequacy of the storage estimates and proposed rules with respect to the operational objectives for each purpose. If the record is short, supplement it with synthetic floods to evaluate flood storage reserves. If necessary, make necessary changes and repeat

testing, evaluating, and changing until satisfactory operation is obtained.

j. Test proposed rules of operation by using sequential routing studies with stochastic hydrologic data to evaluate the possibility of historical bias in the proposed rules.

k. Determine the needs for operating and monitoring equipment required to ensure proper functional operation of the project.

l. As detailed construction plans progress, evaluate cofferdam needs and protective measures needed for the integrity of project construction, particularly diversion capacity as a function of dam construction stage and flood threat for each season.